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Energy trends in the Japanese transportation sector

Nancy Kiang and Lee Schipper[1]

International Energy Studies Program, Energy and Environment Division, Lawrence Berkeley Laboratory, 1 Cyclotron Road, MS 90-4000, Berkeley CA 94720, USA

Passenger transportation in Japan, which is comprised of a high share of rail passengers and a low share of private vehicles, is considered one of the least energy-intensive transportation sectors in the industrialized countries. The thesis of this paper is that, despite low per capita energy use, when the intensities of individual modes are compared, Japanese transportation is *not* more energy efficient. Here, a detailed 25-year energy balance of this sector is analyzed, disaggregating fuel use within the different modes of transport as well as identifying the role of mini-cars and mini-trucks in Japanse transport activity and energy use. Changes in activity, modal structure, and modal energy intensity are separated out to describe energy-consumption trends. (Modal structure is found to be the primary factor behind the current low energy intensity of passenger transport and the high energy intensity of freight.) It is shown, through comparisons with similar data for the USA and eight European countries, that the low per capita energy use for passenger travel in Japan is related to both the low level of travel in general and the great importance of rail and bus, while there is very little difference between the structure of Japanese and European energy use for freight. The increased use of larger private cars and freight trucks continues to raise the energy intensity of the transportation sector, while air transport continues to gain shares in both sectors. Indeed, aggregate travel in Japan is more energy intensive than it is in Europe, and aggregate freight more energy intensive than in either the USA or Europe. Past improvements in energy efficiency were for the most part motivated by commercial concerns. No specific government policies to conserve transportation energy exist, and there is little evidence that policies had any effects on energy use, except, perhaps to increase energy use. The concluding discussion addresses the effects of Japanese transportation energy trends on carbon dioxide emissions.

Keywords: energy trends, Japan, transportation sector

Passenger transportation in Japan — with its high share of passenger rail and low use of private cars relative to other OECD countries — has long been considered among the least energy-intensive of transportation sectors in the industrialized world. Freight transportation, however, is highly energy-intensive on a tonne-kilometer basis because of its reliance on trucks. As a whole, the transportation sector in Japan comprises a larger share of total energy use than does the transport sector in the USA, yet it still consumes less energy per capita. In 1991, the Japanese transportation sector accounted for 29 per cent of the country's energy use, with passenger transport accounting for 15 per cent and freight for 14 per cent; whereas in the USA, transportation took up 39 per cent, passenger transport accounting for 28 per cent and freight 12 per cent. On a per capita basis, the difference in energy consumption for transport is even more dramatic: for passenger travel, Japan consumed 15 GJ/capita/year, the USA 57 GJ/capita/yr; and for freight transport, Japan's energy use was 13 GJ/capita/yr, but in the USA it was 23 GJ/capita/yr. Trends in Japan are now leaning toward greater energy intensity in passenger

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[1] Address correspondence to Dr Lee Schipper, International Energy Agency, 2 Rue Andre Pascal 75775 Paris CEDEX, France, fax 4524 9423, email ljschipper@lbl.gov.

transport, and plans for freight transport may bring continued shifts toward more energy-intensive modes in that sector as well.

In this paper, we analyze energy-use patterns of transportation in Japan and assess changes over the past 25 years, comparing these with other OECD countries. We also discuss the implications of trends in carbon dioxide emissions and discuss opportunities for future reduction in transportation energy consumption. Distinctive to this study are more detailed breakdowns for road vehicles, which for the first time fully account for mini-cars and -trucks.[2] Our thesis is that, despite low per capita energy use in Japan, in comparison with the USA or Europe, transportation in Japan is not more energy efficient when the energy intensities of individual modes are compared. We find little evidence that energy policies per se had any major effect on energy use or energy intensities in Japanese transportation, and we note policies that may have led to increased energy use.

Data sources

Two sources publish data on transportation energy consumption in Japan: (1) the Ministry of Transport (MOT) and (2) the Ministry of International Trade and Industry (MITI) in cooperation with the Energy and Data Modelling Center (EDMC) of the Institute of Energy Economics (IEE). However, only the MOT collects data through direct surveys, whereas MITI and IEE derive figures for energy consumption through indirect calculation. MITI assumes average fuel-intensity levels and derives energy consumption in a top-down fashion, which can be unreliable (Schipper *et al.*, 1993). Of these agencies, only the EDMC performs detailed energy analyses of the country's transportation sector, but few of these studies are published outside of Japan.

Here we use MOT data, making adjustments for the following changes in the data series: before 1981, road vehicle fuel consumption figures are based only on fuel sales data; since 1981, the MOT has conducted surveys, with more modes included in a consistent manner; since 1987, mini-car and mini-truck transport has been counted. A full energy balance of Japan's transportation sector for 1965–91 is presented in Table 1 (passenger) and Table 2 (freight). The tables are broken down by mode and modal fuel types, with mini-cars and mini-trucks also shown. Although some uncertainties still remain, the characteristics of energy use in Japanese transportation are so striking, and the changes observed so large, compared with the uncertainties, that we feel our conclusions are robust.

To avoid confusion, we do not use the word 'automobile', because the Japanese publications, in English or Japanese, often class all motorized road transport (cars, minis, trucks, buses, motorcycles) as 'automobile'. (More details about vehicle classifications are available in an appendix to a Lawrence Berkeley Laboratory Report [LBL-35979, 1995].)

Analytical framework

Our analytical framework for analyzing changes in energy use involves three components:

(1) activity — volume of transportation measured in passenger-kilometers (pkm) and tonne-kilometers (tkm);
(2) structure — modal shares in total activity;
(3) intensity — energy use per loaded transport activity volume.

Additionally, we take note of the composition of fuels and of the vehicle fleet.

These components allow us to separate technological (mode composition, technical efficiency) and non-technological (lifestyle, economic growth) factors. Two aspects of our definition of energy intensity must be kept in mind:

(1) we define *modal intensity* as energy per loaded transport activity (e.g. MJ/pkm, MJ/tkm), which is quite different from *vehicle intensity* (energy per vehicle activity, e.g. MJ/vkm) or *fuel economy* (output/input, e.g. vkm/MJ or miles per gallon);
(2) we believe it is more meaningful to discuss energy intensity in terms of energy per transport activity, rather than per GDP (MacDonald, 1990; Nagata, 1993), because we can separate the energy intensity of each transport mode (in energy/activity) from the GDP intensity of each activity (in passenger-km or tonne-km/GDP).[3]

With regard to the latter, merely looking at the aggregate ratio of transportation energy use to GDP is not very revealing, as Schipper, *et al.* (1992*a*) found when comparing other sectors in Japan. In Japan's transportation sector, at least two of the three factors — activity, structure, intensity — differ significantly from values more commonly found in Europe or the USA.

Calculation of these three effects is done as follows, with 1973 as the base year (Schipper *et al.*, 1992*a*; Howarth *et al.*, 1993).

[2] Transport activity units used in this paper are pkm = passenger-kilometers, tkm = tonne-kilometers, vkm = vehicle-kilometers. Energy is measured in giga-joules (GJ) and megajoules (MJ). For comparison, 1 liter of gasoline contains approximately 32–34 MJ, 1 liter of diesel fuel about 35.6 MJ. Modal energy intensity is measured in units of energy/pkm or energy/tkm, while vehicle intensity is measured as energy/vkm (1 MJ = 0.95 BTU).

[3] 'Energy intensity' will be always be used to mean modal intensity, i.e. energy used per loaded transport activity, e.g. MJ/pkm or MJ/tkm. 'Vehicle efficiency' is the inverse of vehicle intensity, which is energy use per vehicle distance traveled, MJ/vkm. Note that these vehicle units do not necessarily mean that the vehicle is not loaded — vehicle intensity could increase with increasing loads, yet energy intensity could decrease at the same time.

Table 1 Passenger transportation energy use and volume of travel

Passenger energy use (PJ)

Year	Total	Cars: Total	Cars: G-total	Cars: G-Mini	Cars: D	Cars: LPG	Bus: Total	Bus: G	Bus: D	Rail: Total	Rail: D	Rail: Elec	Boat D	Air* Jetf
1965	263	158	124	7	3	31.4	39.0	2.0	37.0	30.6	12.1	18.5	16.6	18.6
1966	310	195	151	9	3	41.2	42.4	2.3	40.1	32.9	12.9	19.9	16.8	23.0
1967	380	255	201	15	3	51.0	45.7	3.1	42.6	37.3	15.8	21.5	18.1	24.3
1968	465	330	266	22	3	60.8	48.5	4.0	44.5	39.7	16.6	23.2	19.2	27.8
1969	550	403	329	31	1	72.1	51.8	5.3	46.5	43.1	18.0	25.1	20.6	32.1
1970	642	477	406	42	1	69.5	56.9	7.5	49.4	46.3	19.3	27.0	22.0	40.0
1971	748	572	493	49	1	77.7	57.2	7.5	49.7	48.4	20.6	27.8	27.2	43.6
1972	778	573	502	54	1	70.7	59.8	8.3	51.4	52.5	22.1	30.4	41.5	50.9
1973	885	660	583	53	1	75.3	60.4	7.6	52.8	54.4	22.0	32.5	54.4	55.9
1974	899	658	581	51	1	75.3	59.1	6.9	52.2	56.7	22.5	34.2	61.0	63.8
1975	946	700	634	46	2	63.6	59.1	6.8	52.2	58.0	22.2	35.8	60.0	69.7
1976	999	745	675	43	4	66.8	60.7	6.5	54.2	60.2	22.8	37.4	61.9	71.1
1977	1094	828	754	42	6	67.8	60.7	6.5	54.1	61.6	22.7	39.0	61.4	81.8
1978	1170	896	814	40	12	69.9	61.7	5.8	55.9	61.7	22.2	39.5	62.5	88.3
1979	1254	973	882	39	20	71.6	62.4	4.7	57.7	62.3	22.4	39.9	60.8	95.4
1980	1285	998	897	38	30	7.10	62.9	4.1	58.8	61.2	21.3	39.9	63.6	98.8
1981	1281	1001	892	37	39	70.5	64.3	3.7	60.6	61.2	20.7	40.5	59.6	94.3
1982	1298	1023	904	37	50	68.7	63.8	3.0	60.9	61.6	19.5	42.1	59.5	89.6
1983	1312	1036	906	36	60	69.7	63.9	2.5	61.4	61.1	18.2	42.9	59.7	90.9
1984	1309	1035	899	36	68	68.8	64.5	2.1	62.4	59.4	15.8	43.6	59.0	90.9
1985	1338	1057	913	35	74	70.1	65.1	1.7	63.4	59.1	14.4	44.7	59.1	97.8
1986	1372	1088	940	33	78	70.4	64.6	1.4	63.2	59.3	13.1	46.2	60.1	100.2
1987	1392	1101	948	35	81	72.8	66.2	1.2	65.0	62.0	12.3	49.7	61.0	101.2
1988	1455	1146	984	34	90	71.7	68.0	0.9	67.1	66.1	12.5	53.6	69.5	105.4
1989	1530	1219	1042	35	107	69.9	69.3	0.8	68.5	68.4	12.8	55.5	64.2	109.2
1990	1642	1315	1115	42	130	70.1	71.3	0.6	70.7	70.6	12.7	57.8	65.6	118.9
1991	1756	1410	1180	58	158	72.1	70.2	0.5	69.7	72.2	12.6	59.6	81.3	122.7
1992	1732	1390	1133	74	186	71.2	72.0	0.4	71.6	71.9	12.5	59.4	70.9	127.3
1993	1783	1434	1156	87	207	70.4	73.0	0.3	72.6	74.5	13.7	60.8	70.9	131.0

Shares in energy (%), Passenger travel (10^9 pkm), Shares in travel (%)

Year	Energy share: Car	Energy share: Bus	Energy share: Rail	Energy share: Boat	Energy share: Air	Travel: Total	Travel: Cars Total	Travel: Cars Minis	Travel: Buses	Travel: Rail	Travel: Boat	Travel: Air	Travel share: Cars	Travel share: Buses	Travel share: Rail	Travel share: Boat	Travel share: Air
1965	60.1	14.8	11.6	6.3	7.1	402	60	4	80.1	255	8.4	3.0	15	19.9	64	0.8	0.7
1966	62.9	13.7	10.6	5.4	7.4	428	79	5	83.9	259	3.5	2.9	18	19.6	60	0.8	0.7
1967	67.1	12.0	9.8	4.7	6.4	478	110	8	90.5	271	3.8	3.9	23	18.9	57	0.8	0.8
1968	70.9	10.4	8.5	4.1	6.0	527	149	12	95.3	274	4.1	5.1	28	18.1	52	0.8	1.0
1969	73.2	9.4	7.8	3.7	5.8	583	196	18	100.2	275	4.4	7.0	34	17.2	47	0.8	1.2
1970	74.3	8.9	7.2	3.4	6.2	654	248	23	102.9	289	4.8	9.3	38	15.7	44	0.7	1.4
1971	76.4	7.6	6.5	3.6	5.8	690	284	28	100.8	290	5.0	10.3	41	14.6	42	0.7	1.5
1972	73.7	7.7	6.7	5.3	6.5	722	294	30	108.2	300	6.7	12.7	41	15.0	42	0.9	1.8
1973	74.6	6.8	6.1	6.1	6.3	772	323	30	111.7	313	7.7	16.0	42	14.5	41	1.0	2.1
1974	73.2	6.6	6.3	6.8	7.1	786	320	28	115.8	324	7.8	17.6	41	14.7	41	1.0	2.2
1975	73.9	6.2	6.1	6.3	7.4	803	343	26	110.1	324	6.9	19.2	43	13.7	40	0.9	2.4
1976	74.6	6.1	6.0	6.2	7.1	809	364	24	98.7	320	6.7	20.1	45	12.2	39	0.8	2.5
1977	75.7	5.5	5.6	5.6	7.5	842	395	24	104.6	312	6.5	23.6	47	12.4	37	0.8	2.8
1978	76.6	5.3	5.3	5.3	7.5	873	421	22	107.0	311	6.4	26.9	48	12.3	36	0.7	3.1
1979	77.6	5.0	5.0	4.8	7.6	905	448	22	108.3	312	6.4	30.3	49	12.0	35	0.7	3.3
1980	77.7	4.9	4.8	4.9	7.7	920	459	21	110.4	315	6.1	29.7	50	12.0	34	0.7	3.2
1981	78.2	5.0	4.8	4.7	7.4	932	470	21	108.8	316	6.0	31.0	50	11.7	34	0.6	3.3
1982	78.8	4.9	4.7	4.6	6.9	943	486	21	104.8	316	5.9	30.1	52	11.1	34	0.6	3.2
1983	79.0	4.9	4.7	4.6	6.9	954	493	20	103.4	321	5.7	30.6	52	10.8	34	0.6	3.2
1984	79.1	4.9	4.5	4.5	6.9	970	503	20	103.1	324	5.8	33.5	52	10.6	33	0.6	3.5
1985	79.0	4.5	4.4	4.4	7.3	996	522	19	104.9	330	5.8	33.1	52	10.5	33	0.6	3.3
1986	79.3	4.7	4.3	4.4	7.3	1018	540	19	101.6	335	5.7	35.9	53	10.0	33	0.6	3.5
1987	79.1	4.8	4.5	4.4	7.3	1049	557	18	102.9	345	5.9	38.5	53	9.8	33	0.6	3.7
1988	78.8	4.7	4.5	4.8	7.2	1101	585	19	107.2	362	5.7	41.1	53	9.7	33	0.5	3.7
1989	79.7	4.5	4.5	4.2	7.1	1155	624	21	109.1	369	5.9	47.1	54	9.4	32	0.5	4.1
1990	80.1	4.3	4.3	4.0	7.2	1223	668	23	110.4	387	6.3	51.6	55	9.0	32	0.5	4.2
1991	80.3	4.0	4.1	4.6	7.0	1271	700	26	108.2	400	6.5	55.3	55	8.5	31	0.5	4.4
1992	80.3	4.2	4.1	4.1	7.4	1301	730	30	106.6	402	6.1	56.7	56	8.2	31	0.5	4.4
1993	80.4	4.1	4.2	4.0	7.3	1305	737	31	102.9	403	6.1	57.1	56	7.9	31	0.5	4.4

PJ — petajoules
pkm — person-kilometers
G — gasoline
D — diesel
LPG — liquified petroleum gas
JETF — jetfuel
Elec — electricity
Cars — private and commercial
Mini-cars — height < 330 cm; width < 140 cm; length < 200 cm; engine displacement < 660 cc
Buses — private and commercial
Rail — Japan Rail and public rail
Boat — domestic
*Air — domestic commercial; energy data source: Energy Data and Modelling Center
Sources: Ministry of Transport and LBL estimates (LBL Report LBL-35979).

Table 2 Freight transport energy consumption and volume of transport

	Freight energy use (PJ)										Shares in energy (%)				Freight transport (10^9 tkm)					Shares in transport (%)			
		Trucks				Rail			Ship	Air	Truck	Rail	Ship	Air		Truck	Rail	Ship	Air	Truck	Rail	Ship	Air
	Total	Total	G-total	G-Mini	D	Total	D	Elec	D	JETF					Total								
1965	436	363	210	45	108	10.8	4.3	6.5	61.4	0.9	83	2.5	14.1	0.2	187	49	57.3	81	0.0	26	31	43	0.0
1966	520	437	242	51	143	10.0	3.1	7.0	70.9	1.3	84	1.9	13.6	0.2	210	66	55.4	89	0.0	31	26	42	0.0
1967	628	527	279	58	190	12.8	5.4	7.4	86.7	1.9	84	2.0	13.8	0.3	245	82	59.0	104	0.0	34	24	42	0.0
1968	703	598	300	62	236	13.6	5.7	7.9	88.5	2.2	85	1.9	12.6	0.3	264	103	59.5	101	0.1	39	23	38	0.0
1969	800	661	323	64	273	15.0	6.2	8.7	122.2	2.6	83	1.9	15.3	0.3	316	121	60.7	134	0.1	38	19	42	0.0
1970	851	688	319	68	301	16.0	6.7	9.4	143.5	3.0	81	1.9	16.9	0.4	352	137	63.4	151	0.1	39	18	43	0.0
1971	893	717	321	66	329	16.4	7.0	9.4	156.8	3.3	80	1.8	17.6	0.4	363	144	62.2	157	0.1	40	17	43	0.0
1972	937	732	316	67	349	16.4	6.9	9.5	184.4	4.6	78	1.7	19.7	0.5	390	155	59.5	176	0.1	40	15	45	0.0
1973	974	724	293	69	362	16.0	6.5	9.5	228.0	5.9	74	1.6	23.4	0.6	408	142	58.3	208	0.2	35	14	51	0.0
1974	969	728	305	61	362	14.5	5.7	8.7	220.8	5.5	75	1.5	22.8	0.6	377	132	52.5	192	0.1	35	14	51	0.0
1975	1027	788	344	64	380	13.3	5.1	8.2	219.8	5.9	77	1.3	21.4	0.6	361	130	47.1	184	0.2	36	13	51	0.0
1976	1095	850	370	68	411	12.6	4.8	7.8	227.1	5.6	78	1.1	20.7	0.5	374	133	46.0	194	0.2	36	12	52	0.0
1977	1121	878	349	75	454	11.9	4.4	7.5	223.9	6.6	78	1.1	20.0	0.6	387	144	41.0	202	0.2	37	11	52	0.0
1978	1165	939	339	83	517	11.3	4.1	7.2	207.5	7.7	81	1.0	17.8	0.7	410	157	40.9	212	0.2	38	10	52	0.1
1979	1214	985	324	95	567	10.9	3.9	7.0	208.5	9.0	81	0.9	17.2	0.7	443	174	42.8	226	0.3	39	10	51	0.1
1980	1205	1009	312	110	587	10.7	3.7	7.0	175.6	10.2	84	0.9	14.6	0.8	442	182	37.4	222	0.3	41	8	50	0.1
1981	1153	1013	292	126	596	10.2	3.4	6.7	119.7	9.9	88	0.9	10.4	0.9	428	183	33.8	212	0.3	43	8	49	0.1
1982	1160	1028	273	142	612	9.5	3.0	6.5	112.0	10.9	89	0.8	9.7	0.9	418	189	30.6	198	0.4	45	7	47	0.1
1983	1185	1051	248	160	643	8.5	2.5	6.0	113.6	11.8	89	0.7	9.6	1.0	424	195	27.4	201	0.4	46	6	47	0.1
1984	1214	1091	228	178	685	7.1	1.9	5.2	103.7	12.7	90	0.6	8.5	1.0	436	203	23.0	210	0.4	46	5	48	0.1
1985	1254	1127	211	197	719	6.6	1.6	5.0	106.0	13.8	90	0.5	8.5	1.1	436	208	21.9	206	0.5	48	5	47	0.1
1986	1314	1186	199	228	758	5.8	1.3	4.5	107.2	15.0	90	0.4	8.2	1.1	435	216	20.4	198	0.5	50	5	45	0.1
1987	1368	1246	180	250	816	4.5	0.9	3.6	101.7	16.1	91	0.3	7.4	1.2	449	226	20.5	201	0.6	50	5	45	0.1
1988	1442	1313	162	258	893	5.1	1.0	4.2	107.0	16.8	91	0.4	7.4	1.2	483	246	23.5	213	0.7	51	5	44	0.1
1989	1487	1352	152	256	945	5.4	1.0	4.4	111.8	17.1	91	0.4	7.5	1.2	509	263	25.1	220	0.8	52	5	43	0.1
1990	1548	1401	148	257	996	5.5	1.0	4.5	123.4	17.3	91	0.4	8.0	1.1	547	274	27.2	245	0.8	50	5	45	0.1
1991	1627	1478	141	262	1075	5.5	1.0	4.6	124.7	17.8	91	0.3	7.7	1.1	560	284	27.2	248	0.8	51	5	44	0.1
1993	1669	1522	134	273	1116	5.6	1.0	4.6	122.9	18.4	91	0.3	7.4	1.1	557	282	26.7	248	0.8	51	5	45	0.1
1993	1677	1534	128	280	1126	5.6	1.0	4.5	117.7	19.6	91	0.3	7.0	1.2	536	276	25.4	234	0.8	52	5	44	0.2

PJ — petajoules
tkm — tonne-kilometers
G — gasoline
D — diesel
JETF — jetfuel
Elec — electricity
Trucks — private and commercial
Mini-trucks — height < 330 cm; width < 140 cm; length < 200 cm; engine displacement < 660 cc
Rail — Japan Rail and public rail
Ships — domestic
Air — domestic commercial
Sources: Ministry of Transport and LBL estimates (LBL Report LBL-35979).

Let:

$E_{t,m}$ = energy consumed in year t by mode m, where mode $m = 1, \ldots, q$;

$A_{t,m}$ = activity (pkm, tkm) in year t on mode m;

$I_{t,m}$ = energy intensity (energy/activity) in year t on mode m;

To find the *activity effect*, calculate what energy use would have been in year t if the energy intensity and modal structure remained the same as in 1973, while only activity varied from year to year. Thus,

$$\text{Total Energy in year } t \text{ due to activity effect} = [\text{Intensity in 1973}] \cdot [\text{Total Activity in year } t]$$

$$= \frac{[\text{Total Energy in 1973}] \cdot [\text{Total Activity in year } t]}{[\text{Total Activity in 1973}]}$$

$$E_t[\textit{activity effect}] = \frac{\left(\sum_{m=1}^{q} E_{1973,m}\right)}{\left(\sum_{m=1}^{q} A_{1973,m}\right)} \cdot \left(\sum_{m=1}^{q} A_{t,m}\right)$$

To find the *structural effect*, calculate what energy use would have been in year t had overall activity and intensity remained at 1973 levels, while the modal shares in activity changed each year:

$$\text{Total Energy in year } t \text{ due to structure effect} = [\text{Total Activity 1973}] \cdot \sum_{m=1}^{q} (\text{Mode activity share in year } t)$$
$$(\text{Mode activity share in year } t) \cdot (\text{Mode Intensity in 1973})$$

$$= [\text{Total Activity 1973}] \cdot \sum_{m=1}^{q} \frac{(\text{Mode Activity, year } t)}{(\text{Total Activity, year } t} \cdot (\text{Mode Intensity 1973})$$

$$E_t[\textit{structure effect}] = \frac{\left(\sum_{m=1}^{q} A_{1973,m}\right)}{\left(\sum_{m=1}^{q} A_{t,m}\right)} \cdot \left[\sum_{m=1}^{q} A_{t,m} \cdot I_{1973,m}\right]$$

To find the *intensity effect*, calculate what energy use would have been in year t had overall activity and modal structure remained the same as in 1973 while only energy intensity changed each year:

Total Energy in year t due to intensity effect

$$= \sum_{m=1}^{q} (\text{Mode Activity 1973})(\text{Mode Intensity, year } t)$$

$$E_t[\textit{intensity effect}] = \sum_{m=1}^{q} A_{1973,m} \cdot I_{t,m}$$

The changes in overall energy use in these three components provide a physical description of energy-saving trends in the country over the past decades, and they reveal where policymakers may most effectively look to reduce energy consumption and carbon dioxide emissions in the future. Note that since the above intensity is defined in terms of passenger-kilometers and tonne-kilometers, rather than vehicle-kilometers, the changes (or not) in load factors are inherently accounted for. In the following sections, we describe the impacts of changes in load factors for particular modes. Thus, with these components in mind, we review changes in passenger and freight transport over the past decade and a half, and at the end of this article provide the activity–structure–intensity decomposition for the entire transportation sector. We further discuss the subtleties and potential errors involved when targeting any one of these factors alone in energy-conservation policy.

Passenger transportation

The Japanese passenger transport sector in aggregate is considered the least energy-intensive of any in high-income OECD countries (Schipper *et al.*, 1992*b*). Low activity levels, a modal structure favoring collective modes, especially rail (31 per cent mode share, compared to US 1 per cent), and high (albeit falling) load factors all reduce per capita energy consumption for passenger travel. However, our analysis finds that the low energy intensity may be misleading, since the sector is shifting from its low energy-intensity configuration. There has been a small amount of fuel switching to diesel for new private cars in response to the improved design of diesel cars with respect to comfort. The most significant trend is that the Japanese are re-determining energy intensity with increased overall travel, including the use of more energy-intensive private cars, less use of bus and rail in total travel, and an increased share of domestic air travel. Because of few collected data, we do not count motorcycle or moped travel, which, in fact, is a significant source of transportation in Japan as in many other Asian countries.

Economic growth, travel, and energy use

Figure 1 shows the relationships among per capita GDP, passenger transportation (pkm, and total MJ for passenger travel), as well as the overall energy intensity of passenger transport. A log scale is used to show relative growth rates. Figure 2 compares intensities of several modes of passenger travel for some key years of the past decade and a half.

The 1960s were a period of motorization in newly industrializing Japan; thus, the growth rates in both passenger travel and accompanying energy use surpassed the growth rate of GDP. Energy use of course increased faster than travel, since the changes included shifts to more energy-intensive modes, i.e. cars. As the

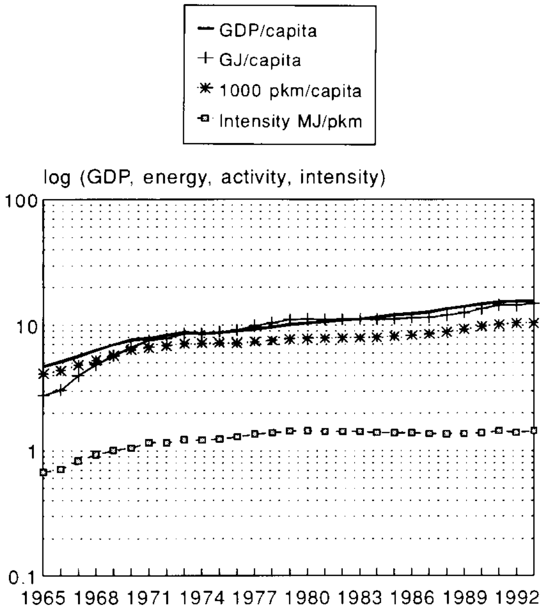

Figure 1 Japan GDP, passenger transportation activity and energy use

economy slowed in the early 1970s, growth in travel slowed in tandem, and then after the energy crisis, passenger travel growth slowed slightly relative to GDP. Thereafter the two continued almost in parallel. Energy intensity clearly improved following the two energy crises, but in recent years volume of travel has begun to accelerate relative to GDP, and energy use relative to travel.

Modal contributions

Total and modal shares of passenger travel and energy use and per capita energy consumption by fuel type and fuel share are shown in Table 1. In 1993, cars accounted for 49 per cent of total passenger-kilometers traveled; buses 10 per cent; rail 36 per cent; boats 1 per cent; and air 5 per cent. While per capita travel for bus, rail, and marine transport has remained stagnant, passenger car and air travel have grown steadily over the past decade. Increased car ownership has boosted the share of cars in total travel, while an enormous expansion in domestic air travel, now spurred by competition, has raised the importance of air travel. Air modal energy intensity has improved (down to 2.3 MJ/pkm in 1993 from 6.2 MJ/pkm in 1965) as travel has expanded and newer planes have been put into the fleet.

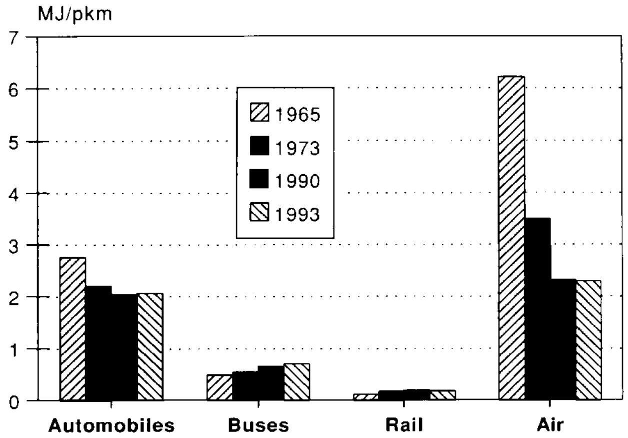

Figure 2 Representative Japanese passenger energy intensities

Passenger car ownership

The role of private cars is undergoing significant changes in Japan and strongly affecting energy use in passenger transport. Per capita car ownership in Japan is currently only half that of the USA. Nevertheless, the trend in car ownership follows on a tripling from 100 cars per 1 000 persons in 1965 (when the USA had 350), of which 7 per cent were commercial cars, to 329 per 1 000 persons in 1993, of which now less than 1 per cent are commercial. Among privately owned cars, there is an increasing share of diesel cars, a declining share of mini cars (cars with less than 660 cc displacement), and a growing share of large cars. (LPG cars are almost exclusively associated with commercial cars and/or taxis, whose per capita stock has not changed much in either number or fuel type — only about 5 per cent diesel since 1977.)

Improvements in the performance of diesel cars, such as reducing their noisiness, have been a main factor in their increasing use (Sagawa, 1992). In addition, recreational vehicles (RV), both gasoline and diesel, have become more popular, thus pushing up the use of diesel fuel overall (Nagata, personal communication). Fuel cost is probably not a strong factor behind fuel switching, because diesel fuel has always been cheaper than gasoline and diesel-powered cars are still generally more expensive, but trends in fuels costs are worth mentioning. Both gasoline and diesel prices have been falling steadily since 1982, but diesel prices have dropped 40 per cent to \$0.30/liter in 1993, whereas gasoline prices fell 30 per cent and, at \$0.53/liter, are 1.7 times higher than diesel.[4]

In recent years, in addition to mini-cars, the Japanese have been buying a greater share of large, more energy-intensive cars. The average engine displacement for on-road cars has grown from 1444 cc in 1980 to 1525 cc in 1990. Vehicle fuel intensity for new cars, which had been decreasing between 1974 and 1982, has been increasing again, according to Japanese tests. To compare, in 1990 German new-car fuel intensity was 7.9 liters of gasoline equivalent per 100 vkm (30 mpg), in the USA it was 9.4 liters/100 vkm (25.4 mpg), and in Japan, 8.7

[4] We converted Japanese prices to real 1985 yen using the Japanese consumer price index, and converted those to US dollars at 1985 purchasing power parity published by the OECD (200 yen = \$1.00). This is a standard procedure for comparing prices (and incomes) between countries.

liters/100 vkm (27.4 mpg). Interpreting tests is risky, even within a single country (Schipper *et al.*, 1993*a*; Schipper and Tax, 1994), but in this case the nearly 35 per cent decline in on-road fuel intensity in the USA and 10–15% decline in the same measure in Germany contrasts with no real trend in Japan since 1982, suggesting that new-car tests correctly indicate that fuel intensity of new Japanese cars has not decreased much in the last dozen years. Some operational and economic policy incentives for the increase in large car ownership include technological standards for the safety of heavier cars and a lowering of the ownership tax in 1989 for cars with engine sizes from 2000 and greater (Nagata, 1993). The largest change occurred for cars with engine sizes of 2000–2500 cc, and ownership of these cars has increased rapidly (Nagata, personal communication). The new tax policy was not a transportation policy, but was introduced by the Ministry of Finance when it replaced several commodity taxes with the consumer tax. The consumer tax on cars now is tentatively higher than on other consumer items (pending a final taxation policy on cars), but the current effect has been a reduction in the tax on cars.

Passenger car travel utilization

In tandem with increases in car ownership, Japanese people are driving more because of lifestyle, social, and microeconomic changes. These include increased leisure driving, the available luxury of larger, air-conditioned cars and 4-wheel drive vehicles, and the growing numbers of female drivers. The average load factor for cars, while declining somewhat during the 1970s, appears to have increased during the past few years because of the greater use of private cars for weekend leisure travel. But the overall result, despite inroads made by diesel, is an increase in the energy intensity of both average on-road and new vehicles.[5] Contributing further to this trend is growing congestion, but the exact effect is difficult to measure directly (e.g. indirectly calculating fuel intensity through estimates of the average speed in congested metropolitan areas can introduce circular assumptions).

Mini-cars

Its convenient size (< 660 cc displacement) has helped revive the popularity of the mini-car for use as a second family car (Sagawa, personal communication). The MOT first began counting vehicle-kilometers and passenger-kilometers of mini-cars and mini-trucks in 1987, and the resulting step-up in all consumption figures can be misleading when reading the data. Since mini-car and mini-truck stock is known, we have here adjusted for minis in the earlier years, based on load factors. In our estimate, we take the average load factor for 1987–91 and use this value times yearly vehicle stock to extrapolate travel figures back to 1965. While assuming load factors to be constant for all these years may be open to question, this method at least permits us to track the contribution of the mini-car to total mobility. We find that the share of private travel taking place in mini-cars has declined, but their recent popularity has not caused average fuel intensity of the fleet to decline. Moreover, what is more important, our adjustment shows that the inclusion of mini-car travel has not caused the accelerated growth in overall travel in recent years. This trend is not merely an aberration caused by the MOT's change in data sampling.

Summary for cars

The net effect of all these changes has been that the vehicle energy intensity of Japanese car travel in 1993 (in MJ/vkm) was almost as high as in 1973, and the loaded intensity (in MJ/pkm) was only 6 per cent lower. Cars now account for more than half of total travel as well.

Buses

Bus travel (passenger-kilometers) has stagnated since 1973, but energy intensity has increased. The impact on modal energy intensity of decreasing vehicle energy intensity (11 MJ/vkm in 1973, 10.5 MJ/vkm in 1993) was more than offset by decreasing load factors (20.4 persons/vehicle in 1973, 14.8 persons/vehicle in 1993), resulting in an overall increase in energy intensity (0.54 MJ/pkm in 1973, 0.71 MJ/pkm in 1993). While buses still provide more than 10 per cent of passenger travel in Japan, the lack of growth in bus travel as well as the growing energy intensity point to the decline in this collective mode, following trends in other industrialized countries.

Passenger rail

Passenger rail has maintained a steady growth of nearly 2 per cent per year in activity (passenger-kilometers) since 1965, and in 1993 it provided 31 per cent of all passenger activity. However, rail has declined in its share of passenger travel from 66 per cent in 1965. Rail is still the prime form of commuter transport, but growth in air travel and in private car use for leisure has outstripped it. The energy intensity of rail travel has increased slightly, in terms of primary energy per person-kilometer (this measure includes the losses incurred in generation and transmission of electricity). Although the aggregate load factor for passenger rail has declined over the last two decades, it has been increasing as a whole since 1980.

Domestic air travel

Domestic air travel is the other passenger mode with growing rather than declining significance. While its share of passenger transport energy consumption has barely changed in the past two and a half decades, air travel's contribution to passenger transport has grown from a share of less than 1 per cent in 1965 to nearly 5

[5] 1 MJ/pkm = 948 BTU/0.62 pmi = 1528.8 BTU/pmi.

per cent in 1993. The bulk of air travel for this island country is, of course, in international flights, but these are not included here. The energy intensity of air travel in Japan has declined as air travel has expanded, resulting from both an infusion of newer, less energy-intensive aircraft and an increase in load factors. Increased load factors were also due to limits on take-off and landing times, which forced the use of larger aircraft (for both passenger and freight). This increase drove down energy intensities for domestic air travel from 6.2 MJ/pkm in 1965 to 2.3 MJ/pkm in 1993. What is remarkable is that this low level is close to that of automobiles.

Summary of travel

Trends in energy use for travel in Japan point away from its past as a country of low travel intensity and low energy intensity. Car ownership and travel have increased with income. The modal mix has shifted markedly to automobiles and air travel. The energy intensities of rail and bus travel increased, that for automobiles barely fell, and only that for air travel declined. Unless government policies are introduced to encourage energy efficiency, either technically or in systems management, these trends toward greater energy use may continue.

Freight transport

Because of a heavy reliance on trucks, Japan's freight sector as a whole is energy-intensive, measured as aggregate energy use per tonne-kilometer. (See Figure 3 for a graphic representation of the growth of freight intensity.) In freight transport, as in passenger, growth in road and air transport dominate current trends.

Economic growth, freight transport, and energy

Figure 4 shows how per capita energy use for freight has fluctuated as it increased with GDP and freight transport (tkm). A log scale shows more clearly the relative

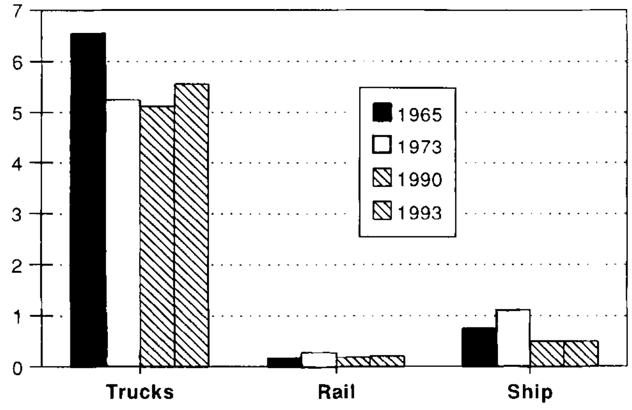

Figure 3 Representative Japanese freight intensities

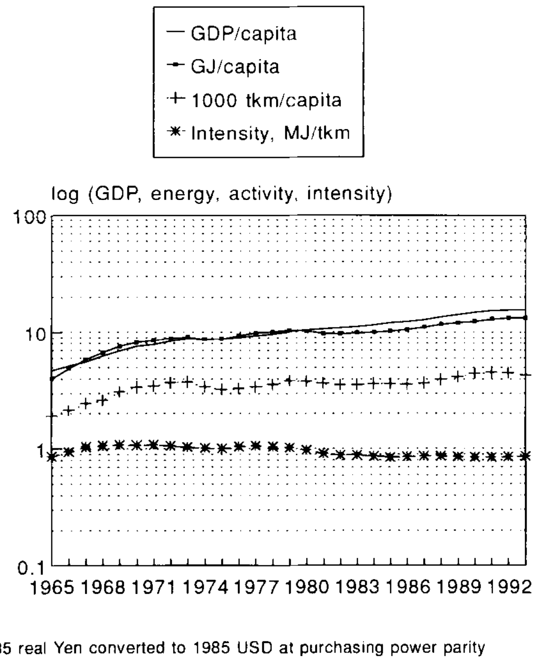

Figure 4 Japan GDP, freight activity, and freight energy use

changes. Motorization and industrialization in the 1960s resulted in steep growth in GDP, freight transport, and energy use, with freight energy use growing faster than GDP. In the 1970s, the energy crisis years were associated with clear declines in freight traffic (but not in GDP). The second oil crisis was followed by a flat period in activity, as freight shifted from rail to trucking; energy consumption remained constant while shifts from non-commercial to more efficient (economically, operationally) commercial trucking were taking place and as goods became generally smaller and lighter (IEE, 1992; Sagawa, 1992). Overall however, the trend in energy consumption and intensity has been an upward one.

Modal contributions

Per capita modal freight activity, energy use, and fuel shares for 1965–93 are shown in Table 2. In 1991 trucks accounted for 52 per cent of total tonne-kilometers; rail 5 per cent; ships 44 per cent; and air less than 1 per cent.

Trucks

Trucks are the dominant mode in terms of both transport share and energy use. The heavy skewing of the freight sector's modal structure toward its most energy-intensive mode is marked, for trucks now move 51 per cent of total tonne-kilometers per year, while consuming 92 per cent of the energy for freight transport. In recent years a greater use of local mini-trucks for frequent deliveries and the increasing congestion in cities have increased the energy intensity (Figure 5) because they carry such small loads. On the other hand, those companies that require frequent deliveries generally

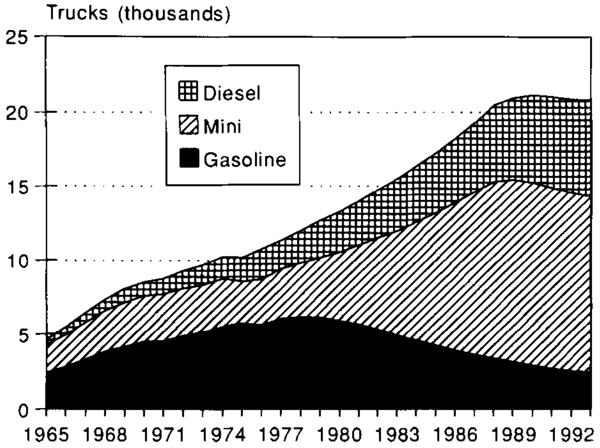

Figure 5 Japanese private and commercial truck stock by fuel type

operate their trucks extremely efficiently (Sagawa, personal communication). The growing use of mini-trucks, which use gasoline, makes it difficult to analyze fuel use in the sector, since diesel does not wholly dominate. Nevertheless, the share of gasoline in freight energy continues to decline, because the growth in transport volume, if not number of vehicles, is still led by large commercial trucks. Another related concern about the heavy reliance on trucks is the difficulty in finding enough truck drivers (Hidaka 1993), but since the recession began (~1991), this scarcity has been negated. An additional statistical issue is that mini-trucks do not clearly belong in either the freight or personal travel categories of transportation, a difficulty similar to that of categorizing personal light trucks in the USA.

Rail

Freight rail activity, by contrast with trucking, has lost shares of total freight tonne-kilometers, from 31 per cent in 1965 to only 5 per cent in 1993. Indeed, actual activity has declined by 50 per cent over that period. Among the reasons for this decline are the change in the nature of freight itself to lighter commercial products and the greater flexibility offered by trucks for just-in-time delivery. Some barriers to increasing the capacity of freight rail are (1) freight rail must share the same rail system as passenger rail — the latter has both more political and more financial power, and (2) land area in Japan is scarce. Currently, the freight rail sector is seeking to increase its capacity not through infrastructure changes but through technological improvements, such as replacing its 1966 locomotives with more powerful ones (Sagawa, personal communication).

Marine

Marine transport, the other significant freight mode, has held a steady share, growing slightly from 43 per cent in 1965 to 52 per cent in 1977, and declining during the past decade to 44 per cent. Total freight ship activity has maintained a slow and decelerating growth rate of 1 per cent per year since 1974. This mode has very low energy intensity, dropping from twice that of rail in 1965 to approximately an equal number in 1991. Factors contributing to decreases in intensity over the decades include a greater use of heavy oils with higher average heating value and improved ship designs, such as hull shapes and the use of paint that reduces resistance. Also, ship energy intensity is proportional to the speed of transport. Energy intensity may be increasing because of increases in the average speed of ships (both Toyota and the MOT are introducing high-speed ships) and greater use of container ships rather than bulk carriers.

Air

The gains made by freight air are still very slight, but they indicate the value of the rapid movement of lightweight, high value-added goods, such as electronics. Also, as noted for passenger air, larger aircraft for freight also increased load capacities.

Summary of the freight sector

The heavy use of trucks drives up modal energy intensity in the freight sector. Mini-trucks are an additional contributing factor. The steady growth of the use of trucks (now used for more than half of all freight transport) has in part hastened the decline of rail freight transport. The use of marine transport has declined steadily but slowly since the mid-1960s. It appears that the characteristics and economic advantages of each mode, and not energy per se, have been the main drivers of modal share, with the flexibility of trucks clearly winning the market share of a pallet of continually lighter and more valuable goods.

CO_2 emissions from transportation in Japan

Fuel switching and modal shifts have strong implications not only for energy intensity but also for emissions of carbon dioxide. Energy intensity versus CO_2 intensity can obviously vary both when comparing fuels and when comparing different modes. For instance, while diesel fuel has a better per liter combustion efficiency than gasoline, it also produces more CO_2 per energy produced. While electric rail is often perceived as an energy-conserving means of mass transport, the actual energy intensity and relative CO_2 emissions depend on the fuel at the generating plant. Our calculations are based on the conversion factors shown in Table 3. These

Table 3 Conversion factors for CO_2 emissions

Transport fuels	($Mt\text{-}CO_2/PJ$)	Power-generation fuels	($Mt\text{-}CO_2/PJ$)
Gasoline	0.069	oil	0.076
Diesel	0.074	natural gas	0.053
Jet fuel	0.072	coal	0.092
Heavy oil	0.077	nuclear	0.000

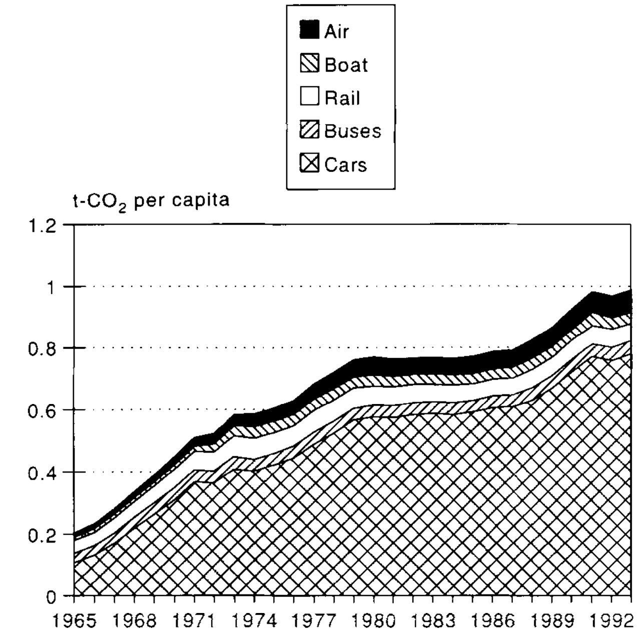

Figure 6 Japanese passenger transport CO_2 emissions per capita by mode

rough figures are based on average fuel qualities, and in the case of power generation, average power plant characteristics.

Figure 6 shows the modal contributions and shares of CO_2 emissions from passenger transport. The total 1991 emissions from passenger transport were 33.4 Mt-carbon, or 0.27 tonnes-carbon per capita. Shares in per capita CO_2 emissions were from cars 80 per cent; buses 4 per cent; rail 5 per cent; boats 4 per cent; and air 7 per cent. Comparing energy shares, we find that buses, boats, and air account for the same share as with CO_2, but cars consume 77 per cent and rail 9 per cent of energy for passenger transport. Here, CO_2 emissions from electricity generation are based on average power plant characteristics for the entire country. Japan railway uses some of its own electricity generated by hydropower not available to other electricity consumers.[6]

We calculate carbon dioxide emissions from freight transport in the same way as for passenger travel. Figure 7 shows CO_2 emissions by freight mode. Total emissions for freight in 1993 were 32.3 Mt-C and 0.26 tonnes-C per capita. Modal shares of emissions for trucks were 91 per cent; rail 1 per cent; ships 7.1 per cent; and air 1.1 per cent. These figures differ little from energy-consumption shares. Rail freight transport does not necessarily make use of dedicated hydroelectricity like passenger rail does, and it contributes a greater share of carbon dioxide emissions than its energy share, with electric rail both more energy-intensive and CO_2-intensive than diesel; however, trucks remain more than five times as CO_2-intensive per tonne-kilometer. Ships are both the least energy- and CO_2-intensive.

In general, trends in CO_2 emissions run parallel to energy trends. Because fuel switching has had a small impact, CO_2 emissions for travel have kept pace with energy use for travel and likewise for freight. The slight departures, however, indicate how important the fuel mix can be in affecting CO_2 emissions from transportation and in assessing strategic options for combatting global warming. In policy-making with regard to both energy consumption and carbon dioxide emissions, the tradeoffs need to be weighed between promoting fuel switching or modal shifts.

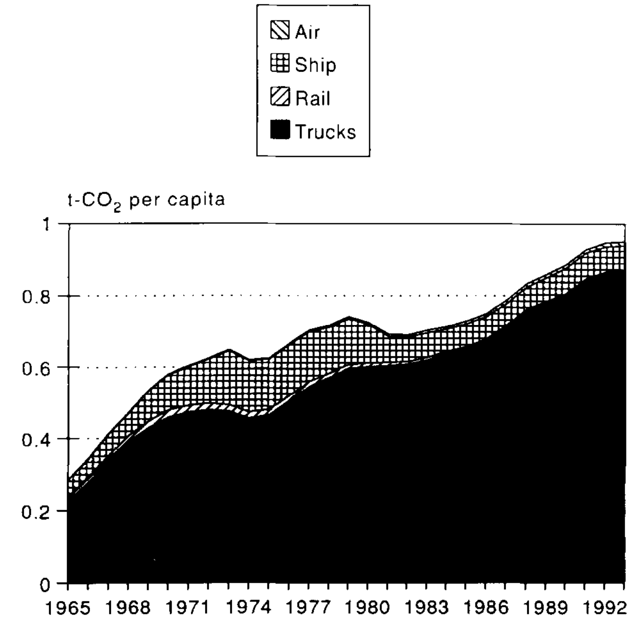

Figure 7 Japanese freight transport CO_2 emissions per capita by mode

Summary of changes in energy use and CO_2 emissions

We can now apply the indices introduced in the first part of the paper to estimate the importance of various components of transportation energy use over time. Figure 8 shows what the overall energy consumption would have been in 1991 for Japan's entire transportation sector, had only one of the three factors named above — activity, structure, intensity — varied since 1973. Total energy consumption for transportation increased, from 18 GJ/capita in 1973 to 28 GJ/capita in 1993, largely because energy use in all modes except rail freight showed significant increases. The 'intensity'

[6] Japan Rail's fuel mix for electricity is not exactly the same as the average for the country, since it makes use of dedicated hydroelectricity. We found, however, the difference to be small for estimating CO_2 emissions, given electric rail's very low share in overall transportation energy consumption, and given the declining share of hydroelectricity in Japan Rail's total energy consumption. This dedicated hydroelectricity accounts for only 7 per cent of total rail electricity use, while for the electricity sector as a whole, hydro accounts for 4 per cent of energy production. We took account of this hydro in calculating emissions from travel.

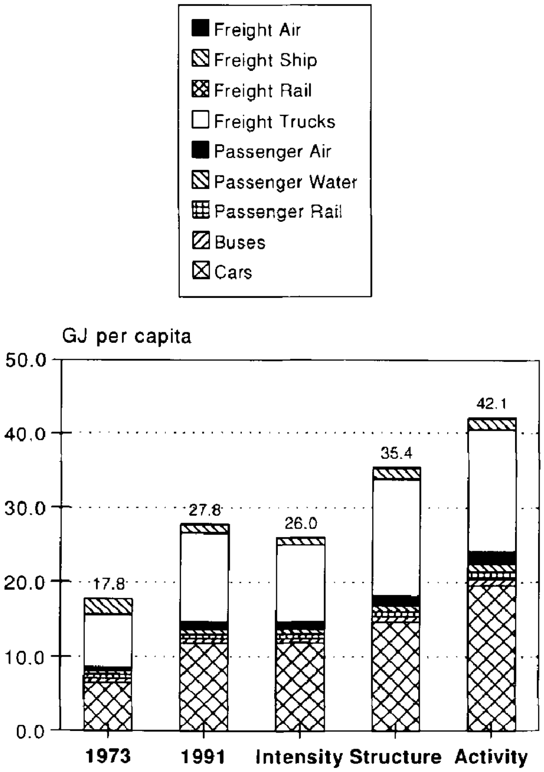

Figure 8 Effects of intensity, structure, and activity on per capita transport energy in Japan

effect shows that, without changes in modal structure or activity volume, changes in the energy intensities of 1993 would have served to decrease energy consumption by 5% (thus the 'intensity' bar is shorter than the 1973 bar). Virtually all of this decline occurred in the freight sector. Structural change boosted energy use in both travel and freight by 26 per cent and 33 per cent, respectively for an average of 30 per cent, while the increase in activity boosted energy for travel. On balance, per capita energy consumption for travel rose sharply, while that for freight declined.

Figures 9 and 10 provide time series of activity–intensity–structure factorial trends for passenger and freight transport, respectively, with GDP growth shown for comparison. Again, a dropping intensity curve but rising structure and activity curves explain the net overall increase in actual energy consumption. We see that the increase in total energy consumption by transportation from 1 934 PJ in 1973 to 3 546 PJ in 1993 was brought about both by increasing travel volume and changes in modal structure. Reductions in energy intensity are small, not nearly enough to counteract these effects. Passenger travel had a greater impact than freight transport on the overall increases in energy use. From 1965 to 1993, passenger activity grew 3.2 times and aggregate intensity 2.1 times, while freight activity and intensity grew less, increasing 2.8 times and 1.5 times respectively.

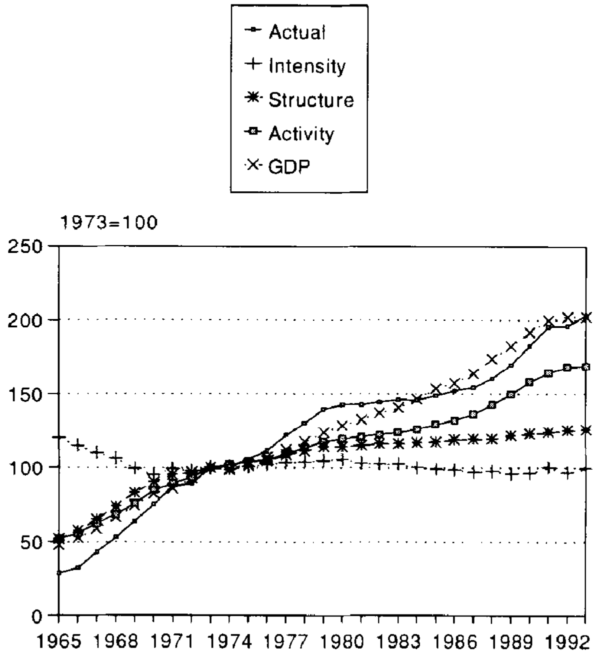

Figure 9 Japanese passenger transport energy consumption

Familiar momentary dips in the actual energy-consumption curve can be seen following the two energy crises in 1973 and 1978, and the factorial curves show when and in what ways the country responded. It is clear now that in recent years, passenger activity is accelerating relative to GDP, and freight activity is running parallel to it.

The analysis of components of change in CO_2 emissions are almost identical to those for energy. Higher

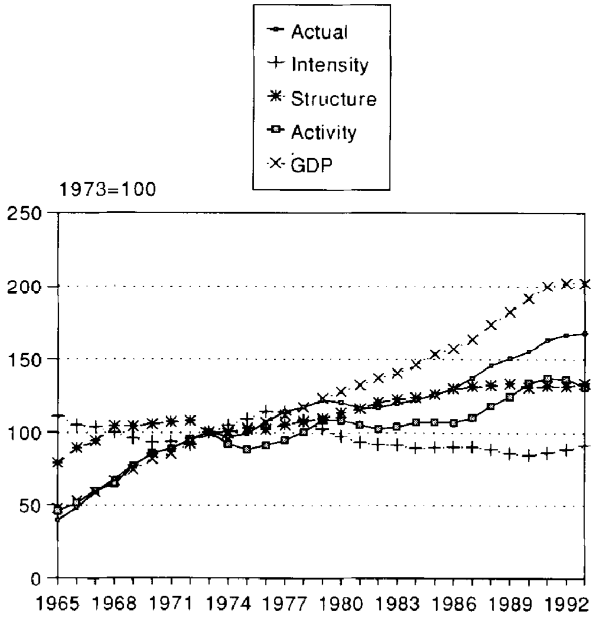

Figure 10 Japanese freight transport energy consumption

Table 4 Energy use for transportation in Europe, the USA, and Japan

		EU-8 1973	EU-8 1992	% Change 91/73	USA 1973	USA 1993	% Change 91/73	JAPAN 1973	JAPAN 1993	% Change 91/73
Passenger energy use										
Energy/Capita: Total	GJ	11.87	19.01	160	60	57	94	8.61	14.76	171
Car	GJ	10.73	17.36	162	54.41	49.96	92	6.56	12.20	186
Bus	GJ	0.50	0.76	153	0.54	0.74	137	0.56	0.59	105
Rail*	GJ	0.45	0.47	106	0.29	0.33	115	0.50	0.60	119
Air	GJ	0.20	0.42	212	5.02	5.70	114	0.51	1.05	204
Travel/Capita: Total	Pass-km	8038	11 886	148	19 590	22 077	113	6405	8949	140
Car	Pass-km	6384	9858	154	17 722	18 843	106	2977	5871	197
Bus	Pass-km	842	1006	120	690	844	122	1028	858	83
Rail	Pass-km	765	887	116	160	157	98	2880	3235	112
Air	Pass-km	47	134	285	1019	2233	219	148	456	309
Energy Intensity, all Mo	MJ/pass-km	1.48	1.60	108	3.08	2.57	84	1.41	1.71	122
Car	MJ/pass/,m	1.68	1.76	105	3.07	2.65	86	2.20	2.08	94
Bus	MJ/pass-km	0.59	0.76	128	0.79	0.88	112	0.54	0.68	126
Rail*	MJ/pass-km	0.58	0.53	91	1.81	2.12	117	0.17	0.18	106
Air	MJ/pass-km	4.20	3.13	74	4.92	2.55	52	3.49	2.30	66
Freight energy use										
Energy/Capita: Total	GJ	6.52	9.21	141	19.10	23.50	123	9.26	13.19	142
Truck	GJ	5.42	8.41	155	14.46	20.14	139	6.83	11.94	175
Rail*	GJ	0.46	0.26	56	2.81	1.76	63	0.29	0.10	36
Inland Ship	GJ	0.64	0.54	84	1.68	1.41	84	2.09	1.01	48
Air	GJ				0.16	0.18	116	0.05	0.14	265
Domestic Freight/Capita Total		3.38	4.16	123	14.43	17.08	118	3.74	4.52	121
Truck	1000 tonne-l	1.80	2.65	147	4.50	6.34	141	1.30	2.29	176
Rail	1001 tonne-l	1.00	0.79	79	5.87	6.10	104	0.53	0.22	41
Inland Ship	1002 tonne-l	0.59	0.72	123	4.03	4.58	114	1.90	2.00	105
Air	1003 tonne-km/ capita				0.03	0.05	203	0.00	0.01	476
Energy Intensity, all Mo	GJ/tonne-km	1.93	2.21	115	1.32	1.38	104	2.47	2.92	118
Truck	GJ/tonne-km	3.02	3.18	105	3.21	3.18	99	5.24	5.22	99
Rail*	GJ/tonne-km	0.46	0.33	70	0.48	0.29	60	0.54	0.48	88
Inland Ship	GJ/tonne-km	1.09	0.75	69	0.42	0.31	74	1.10	0.50	46
Air					5.72	3.29	57			

*Electricity is counted at 3.6 MJ = 1 kwh
The EU-8 include the former West Germany, Great Britain, France, Italy, Finland, Norway, Sweden, and Denmark
The three factors are decomposed holding the 1973 values for the others constant (see fuller explanation in the text).
Source: Lawrence Berkeley Laboratory.

levels of activity and modal shifts both increased the CO_2 intensity of travel and freight and boosted total emissions. The energy intensities of travel increased, and with the CO_2 emissions, while changes in those for freight led to a 10 per cent decline in CO_2 emissions.

Brief international comparison

Some international comparisons will help provide perspective on Japan's transportation energy use, in terms of the three descriptive factors — volume, structure, and intensity. Table 4 shows transportation energy use in the USA, Japan, and eight countries in Europe (EU-8) in 1973 and 1992 or 1993.[7] Of these countries, in passenger transport, Japan had the lowest per capita energy use in 1993, resulting from a low per capita volume of travel and a modal structure characterized by a high share of rail and bus (the modes with lowest energy intensities). Note, however, that passenger air in Japan is likely to be a far more significant mode than the domestic air travel figures shown in Table 4, since foreign air travel by the Japanese is probably a much higher fraction of the country's total air travel, compared to the USA and Europe; however, statistics on foreign air travel by Japanese are not available. Comparing the countries in terms of modal energy intensities, for both bus and rail travel, Japan had its lowest energy intensities in 1993. However, the modal intensity of passenger car travel was virtually equal to that in the USA, and the vehicle intensity of Japanese cars was second only to that in the USA.[8]

In freight transport, Japan's per capita volume of freight in 1991 was lower than that of the USA and higher than the EU-8's,while its overall energy intensity was considerably higher than that of both Europe and the USA. Japan's comparatively high freight energy intensity was due to the significant role of trucking,

[7] Figures for the USA and Europe are based on Schipper *et al.* (1992*a*), Schipper *et al.* (1993) and revisions thereafter. The eight countries in Europe are the former West Germany, Italy, Great Britain, France, Sweden, Denmark, Norway, and Finland.

[8] 1993 vehicle intensities were: EU-8, 9.2 liters/vehicle-kilometer (25.3 miles per gallon); USA, 11.8 l/vkm (20.1 mpg); Japan, 10.5 l/vkm (20.1 mpg). *Source*: Lawrence Berkeley Laboratory, as reported in Davis, S. (1996) *Transportation Energy Data Book*, edition 16 forthcoming, Oak Ridge: Oak Ridge National Lab.

which had a modal share much higher than trucking in the USA while slightly lower than in Europe, and which had a modal energy intensity higher than that of both the USA and Europe. In addition, the intensity of Japanese freight rail was the highest of the countries, while that of domestic shipping was intermediate between the USA and Europe. Consequently, per capita freight energy use in Japan was intermediate between the USA and the EU-8.

Decomposing the changes in these figures over time shows several parallel trends among the countries, with Japan often exhibiting the greatest exaggeration of higher energy-consuming trends. For travel, aggregate energy use grew most sharply in Japan because of both increased volume and a significant shift from bus and rail towards cars. The modal shift in Japan towards cars was greater by far than that in any other country. This growth is understandable, though, given the fact that Japan closed the gap in car ownership from around 1/3–1/2 as many cars per capita in Europe to about 2/3–4/5 as many. Energy intensities (at the 1973 modal mix) fell by 18 per cent in the USA but fell only slightly or increased in the European countries and Japan, respectively (Schipper, 1995). In all countries, higher intensities for bus and rail probably resulted from lower load factors (except for rail in Europe). Domestic air travel grew dramatically, doubling in the USA and nearly tripling in the EU-8 and Japan. Meanwhile, decreasing air energy intensities in all three regions allowed for accompanying slower growth in passenger air energy consumption relative to travel volume. The decrease in air energy intensities was due to technological improvements and increased load factors; these parallel improvements among the countries reflect the international nature of airplane technology, as, for instance, much of the equipment that the Japanese use is American made. Overall, 1973–91 trends in modal energy intensities, travel volumes, and structural shifts all served to increase Japan's per capita energy consumption for passenger transport, and these upward trends were each greater than those in either the USA or the EU-8.

For freight, roughly half of the countries became more energy-intensive and all became more energy-consuming over time, because of shifts to trucks or the capture of new freight markets by trucks. As with cars, the shift to trucks in Japan was more marked than in the other regions. The intensities of rail and ship fell in all countries. Tracking growth in the volume of freight, overall energy use in Japan grew as much as in Europe and faster than in the USA.

It may be erroneous to compare countries with different initial starting conditions this way, and the size and density of a transportation region also affect transport energy consumption. But it seems that, at least in passenger transport, patterns of travel and resulting energy use are converging somewhat. And in freight transport, the trends from 1973 to 1992 in Japan were comparable to those seen elsewhere. However, Japan still consumes considerably less energy than Europe and far less than the USA. We see that the principal difference arises because the *volume* of activity is lowest in Japan, the modal mix for travel which is most weighted towards rail and bus.

Is Japan's system, then, in its ecological interactions, an 'energy efficient' transportation system from which other industrialized countries may learn (including land use and population patterns that are part of the system)? Or, in evolutionary terms, is the low per capita energy consumption relative to the other regions a result of late industrialization that only now has permitted a burgeoning growth in the car population? Answers to these questions require a rethinking of the meaning of 'efficiency' in transportation as well as speculation about the path of modernization. From our comparisons with other countries, it appears that the answers to both of the above may be 'yes', that some aspects of Japan's transportation system enable the country to keep down its energy consumption through low volumes of activity, but that high modal intensities and trends still are warnings of the need to stem rising energy use.

Opportunities for more efficient energy use in transportation

Factors explaining and driving Japan's energy situation and trends show the greater complexity of interactions involved and these must be considered in broad context when considering opportunities for more efficient energy use. Following the energy crises, energy cost had a strong impact on immediately reducing the volume of activity. Commercial motivations explain the 'low' transport energy intensities of rail and air resulting from improved technological efficiency over the years as well as heavy utilization through increased capacities. On the other hand, energy cost has appeared to a less important factor in competitive advantage than operational convenience and other market forces in much of the modal substitution we traced from 1965 to 1973 to 1991; for the modes gaining share (trucks, car, air) were faster or more economic, even if they required more energy. Higher incomes, lifestyle preferences, and changing roles in households, rather than energy worries, are permitting, motivating, and in some cases requiring that people own and use cars that are now affordable, faster, larger, and more comfortable (or smaller and easier to park), or easy to use for suburban shopping. Indeed, despite high gasoline and diesel prices comparable to those in Europe, the Japanese continue to shift to more energy intensive modes. Thus, transportation demand is now driving energy use, rather than the other way around. Geographical characteristics, meanwhile, due to Japan's limited land area, dense urban patterns, and crowded downtowns, assist the high utilization of bus and rail in Japan compared to the USA.

At a national, aggregate level it is simple to suggest that an energy-efficiency policy with respect to transportation should seek to decrease the energy intensity of all transport modes and perhaps encourage a shift of activity away from the most intensive modes. Even in following these general approaches to energy conservation, there are subtleties involved. The three factors of volume, structure, and intensity cannot, of course, be targeted separately from the others, since they are interdependent (Hidaka, 1993; Sagawa, 1992). Affecting these descriptive factors are many driving forces: economics, lifestyle, technology, government programs, geographical constraints, traffic conditions, and links between modes. All these descriptive and driving factors feed back on each other, with different driving strengths depending on a situation.

For example, a modal shift from road to rail transport may result in increased distances traveled, depending on rail access points. Energy intensity can depend on the specific qualities of a route. Intermodal dependence also cannot be neglected, especially with freight, rail, and ship connections with trucking delivery. Further complexities must be taken into account, such as indirect energy use in construction and maintenance of facilities like rail stations, roads, vehicle production, and so on. Hidaka (1993) and Sagawa (1992), in their technological bottom-up studies, emphasize the importance of a long-term policy approach, consideration of social context, and case-by-case examinations in the implementation of modal shifts.

The composition of the passenger and freight transport sectors in Japan demonstrates the importance of modal structure in any country's overall transport energy intensity. Trends show increasing activity and intensity in car, bus, and passenger rail transport, and recent policy has been favoring a modal shift toward both more and larger cars. In freight transport, intensities have been improving little, but modal shifts are once again towards the more energy-intensive modes. Given the driving forces described above, what role do the government's energy policies currently play, or might they play, to actually keep down (or increase) Japan's transport energy intensity? The country's industrial policies have led to great improvements in the productivity of industrial energy use for the sake of competitiveness, and there have been some efforts to improve the efficiency of residential energy, but thus far there is no energy policy with respect to transportation.

Thus far there has been little effort by Japanese authorities to develop a transportation–energy policy. If Japan is to have such an energy policy with respect to transportation, policymakers must address the current institutional setup that is a barrier to more modal competition, as well as policies that may currently lead to increased energy intensities for transport. These problems are certainly not unique to Japan, as can be seen by recent US efforts to better coordinate transportation planning and environmental goals through the Intermodal Surface Transportation Efficiency Act of 1991 and the Clean Air Act Amendments of 1990; these pieces of legislation call for greater cooperation among regional planning agencies. In Japan's case, the jurisdictions of various agencies introduce the following biases and contradictions into transportation planning: the Ministry of Transportation is responsible for rail and navigation, and thus favors these modes; the Ministry of Construction is responsible for roads, such that its goals are increased construction (thus favoring cars and trucks); and local governments promote buses. Meanwhile, the Ministry of International Trade and Industry concentrates mostly on the supply-side of industry, leaving the question of roads and building energy consumption to the Ministry of Construction, whose traditional role has been to build more (Sagawa, personal communication). This jurisdictional division and need for coordination among government agencies that affect transportation must be addressed if the country is to have an energy policy that takes into account energy conservation and global-warming issues.

Conclusions

Our analysis shows that increased travel and modal shifts to automobiles drove up energy use for travel in Japan from 1965 to 1993, while the energy intensity of travel increased. The same factors had a smaller influence on energy use for freight, while energy intensities for freight fell, somewhat restraining energy use in this sector of transportation. As a result freight, which accounted for the majority of energy use in transportation before 1973, ceded its dominance to travel by the mid 1970s and thereafter. Lifestyle changes, afforded by higher incomes, helped drive the shift towards automobiles (and air travel), while competitive forces have significantly reshaped the mix of freight modes in favor of trucking. Government programs so far have served primarily to follow these trends. These forces pushed growth in energy use for transportation in spite of two oil crises.

- Passenger travel is experiencing a modal shift towards more passenger cars and thus greater energy intensity. Passenger cars themselves are becoming more energy-intensive, although a rise in load factors has probably offset this trend in the most recent years.
- The dominance of trucks has brought about the high energy intensity of freight, and this modal structure is unlikely to shift to the less energy-intensive mode of rail because of the limited land area in Japan and the greater power of the passenger rail sector over the use of the rail lines.
- Air travel and air freight are steadily increasing their shares in passenger and freight transport respectively.

- Lifestyle and commercial product changes are bringing increases in the shares of mini-cars and mini-trucks in transport activity, as well as contributing to overall increases in activity that more than offset any energy savings arising from use of these smaller vehicles.
- International comparisons show that most of the modes of travel and freight in Japan are as energy intensive as or more energy intensive than their counterparts in the USA or Europe. It is the low level of total travel and the higher share of bus and rail travel that keeps down energy use for travel in Japan so much relative to these other regions. Per capita energy use for domestic freight in Japan is roughly equal to that in Europe.
- There is not yet any official government policy or coordination among government agencies to try to conserve the energy consumed by transportation. Some recent policy actions have actually indirectly stimulated the purchase and use of larger cars. Improvements in technical efficiency have for the most part been commercially motivated or offset by other changes. For example, the improvements in the technology of automobile propulsion have been offset by increases in car power and size and a decay in traffic conditions.

From our findings here, it appears that Japan's current low energy use for transportation is actually not due to a Japanese acumen for efficiency or to a conscious, progressive effort by government and the commercial sector, as is commonly assumed. Rather, it may be the result of other circumstances whose energy-conserving influences are now eroding. Further study is needed to understand better how Japanese transportation is affected by high population density, urban form, the structure of commercial enterprises, and the role various government incentives played in shaping Japan's transportation sector, which is converging slowly with the structure of systems in other industrialized countries.

Currently, in both passenger and freight transport, both increased transport activity and structural trends are increasing the energy intensity of transportation in Japan. Plans for the future may exacerbate these trends. The Trans-Tokyo Bay Highway, due to open in 1996, will serve the convenience of cars and trucks, and over the next 20 years, the Metropolitan Expressway Public Corporation plans to add another 100 kilometers of roadway to the Tokyo area. Freight transport may possibly undergo a structural shift toward rail far in the future, if some ambitious (and at this point, far-fetched) proposals to build a subway network especially for freight are approved (O'Neill, 1993). Overall, like the rest of the industrialized world, transportation in Japan is moving away from its low energy use of the recent past toward greater activity, travel autonomy, and energy intensity.

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